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STUDIES OF AIRCRAFT NOISE EFFECTS (NASA)
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LABORATORY AND COMMUNITY STUDIES OF AIRCRAFT
NOISE EFFECTS

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SUMMARY

The objective of the noise effects program being conducted by the NASA is to develop aircraft noise criteria and noise reduction methods for achieving greater community and passenger acceptance of air transportation systems. The approach consists of laboratory tests to subjectively evaluate the properties of aircraft-generated noise that are responsible for causing annoyance and field surveys to study the broader problems of community and passenger acceptability.

The program is organized into two major thrusts: community acceptance and passenger acceptance. The community acceptance program includes subjective response studies of single and multiple aircraft overflights as well as longer term community noise exposure. Emphasis is on the development of units and indices which accurately quantify annoyance. The passenger acceptance program includes studies to determine acceptable levels of interior noise and vibration for speech intelligibility and comfort of crew and passengers.

The quantification of single-noise events including the certification of aircraft for compliance with noise standards is discussed. Judgments of the relative noisiness of supersonic transport, commercial-service aircraft, and helicopters having various degrees of impulsiveness are presented. Results

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suggest an accuracy of about ± 3 dB in predicting the noisiness of fixed-wing aircraft using EPNL as the noise unit. Corrections to EPNL to account for helicopter blade slap are also discussed. With respect to the quantification of multiple events, laboratory data are presented in terms of the percentage of subjects highly annoyed as a function of L_{eq} for sessions of aircraft noise and traffic noise presented separately and in combination. The combined data are found to deviate significantly from the trends set by the condition of aircraft and traffic judged separately. In the majority of combined conditions, the percentage of highly annoyed exceeded that predicted by an equal energy or L_{eq} type model.

A community study of aircraft noise and noise-induced building vibration conducted as part of the Concorde monitoring program is discussed. Data define a threshold of building vibration detection in terms of floor vibration level for seated subjects. Results imply that aircraft-generated outdoor sound pressure levels greater than 100 dB (unweighted) can induce structural vibration of a magnitude sufficient to exceed the threshold of vibration detection for occupants inside their homes.

Passenger acceptance data illustrate the interactive effects of noise with multifrequency and multiaxis vibration. Constant comfort contours for various combinations of noise and vibration are presented and the incorporation of these results into a user-oriented model is discussed.

INTRODUCTION

This paper presents an overview of the program being conducted by the NASA on the effects of aircraft noise on people. The objective of the program is to develop aircraft noise criteria and noise reduction methods for achieving greater community and passenger acceptance of air transportation systems. The approach involves laboratory tests to subjectively evaluate the properties of

aircraft-generated noise that are responsible for causing annoyance and field surveys to study the broader problems of community and passenger acceptability including psychological and sociological factors.

The program is organized into two major thrusts: community acceptance and passenger acceptance. The community acceptance program includes subjective response studies of single and multiple aircraft overflights as well as longer term community noise exposure. The passenger acceptance program includes studies to determine acceptable levels of interior noise and vibration for speech intelligibility and comfort of crew and passengers.

Laboratory facilities and field procedures for human response studies are shown in figure 1. Facilities include an exterior and interior simulation area and a passenger ride quality simulator. The exterior simulation area is an auditorium-like room having a multichannel audio system capable of reproducing noise signatures with realistic direction and movement of the source. The interior simulation area is configured as a living room in a house and is used for obtaining the subjective response to noise signatures as they would be heard indoors. In addition, vibration exciters are used to simulate noise-induced vibrations associated with aircraft overflights. The passenger simulator is configured to represent the interior of an aircraft. In addition to noise inputs provided by multiple interior speakers, the simulator is equipped with hydraulic actuators to provide motion in the vertical, lateral, and roll directions over a frequency range from 0 to 50 Hz. Field studies include both controlled flyover studies as well as surveys in airport communities where both subjective response and noise/vibration environments are recorded.

Selected results from several recent studies are presented herein to indicate the nature, scope, and methods of the research program.

COMMUNITY ACCEPTANCE

Emphasis is on the development of units, indices, and models which accurately quantify the annoyance to single and multiple overflights and community response, respectively. Single-event studies have examined in detail the effects of low-frequency, duration, and impulsiveness (helicopter and propeller aircraft, for example) while the multiple-event studies have examined the tradeoff of noise level and number of events and the quantification of combined noise environments. The most recent community studies involved aircraft noise-induced building vibration.

Single Events

The accurate quantification of single-noise events is important to noise reduction studies, to the development of multiple-event indices, and to the certification of aircraft for compliance with noise standards. With respect to certification, the noise measurement unit must properly discriminate between aircraft. Recent examples of this concern involved supersonic transport certification and pending helicopter certification. Subjective studies were conducted to examine the effectiveness of existing units for describing such aircraft.

The predictive ability of some of the more common noise descriptors for quantifying the noise of supersonic transport relative to other airplanes was examined using aircraft recordings. In the experiment (ref. 1), 96 subjects made numerical-category judgments of 120 recorded airplane noise stimuli in the simulated outdoor acoustic environment. The noise stimuli included takeoff and landing operations of a DC-8 turbofan, DC-8 turbojet, B-747, B-737, CV-640 turboprop and Concorde. The recordings were made at FAR 36 certification

measurement distances and were, therefore, representative of locations close to an airport. The noise of each airplane type and operation was presented to the subjects twice during the experiment at each of five levels spaced 8 dB apart. The subjective data were analyzed in terms of equal noisiness or annoyance potential for each airplane type and operation. A representative sample of the equal noisiness levels is presented in figure 2 where the ordinate is the level in terms of EPNL which produced the condition of equal judged noisiness for each airplane type. For bars below the mean, EPNL underestimates the annoyance potential and for those above the mean, EPNL overestimates the annoyance potential. For example, EPNL underestimates the noisiness of the Concorde by about 3.5 dB and has a spread of about ± 3 dB across all airplanes.

The main purpose of the helicopter experiment (ref. 2) was to provide general information on the need for an impulsiveness correction for helicopter quantification and/or noise certification. The experiment was conducted at the NASA Wallops Flight Center where subjects judged the noisiness of helicopter overflights. The impulsive characteristics of one of the helicopters was controlled by varying rotor rotational rate while other variables such as duration and level remained relatively constant. The experimental design was factorial with four flightpaths, (two altitudes, two angles of elevation), three levels of relative impulsiveness, and two replications. Data from 40 subjects indicate that within each altitude and sideline distance condition, the level of impulsiveness is positively correlated with noisiness. Across helicopter types and flight conditions, however, the addition of an impulsiveness correction does not significantly improve the correlation between the noisiness judgments and the predictive measure, EPNL.

Multiple Events

Several recent studies have relied on the precision of the laboratory test situation to examine the tradeoff of aircraft noise level and number of exposures and to investigate the use of various cumulative noise exposure measures as unifying indices for different noise sources (refs. 3 and 4). In addition, the effects of combined noise sources on community annoyance were studied, ref. 5. In the latter study, subjects were exposed to and judged extended sessions of separate and combined noises of aircraft and ground traffic. Data are shown in figure 3 in terms of the percentage of subjects highly annoyed as a function of L_{eq} . The symbols represent data from sessions in which aircraft and traffic noises were presented simultaneously. The combined data deviate significantly from the trends set by the conditions of aircraft and traffic separately. In the majority of combined conditions, the percentage highly annoyed exceeded that predicted by an equal energy or L_{eq} type model. This behavior is indicative of an interaction between noise sources. A model of multiple source annoyance was subsequently developed that provides the necessary summation of, and inhibition between noise sources.

Community Response

The most recent community response study examined noise-induced building vibration. This issue was raised with the initiation of Concorde operations into the U.S.A. and subsequently became part of the Concorde environmental monitoring program, ref. 6. In addition to extensive window, wall, and floor vibration measurements, limited subjective studies were conducted to examine human detection and annoyance of combined noise and vibration.

Subjective test sessions of approximately 1-hour duration were conducted in several homes using the subjective response rating form shown in figure 4. Following each flyover, the subjects indicated whether or not they detected vibration, rattle, or noise; whether or not the vibration, rattle, or noise was annoying; and finally an overall annoyance rating of the flyover on a numerical-category scale. The results of this phase of the experiment are shown in figure 5 in which vibration detection is plotted as a function of vertical floor vibration. The threshold of vibration detection, defined as the level at which 50 percent of the observers perceived the vibration, appears to be in the range of from 62 to 68 dB, vertical floor acceleration. This range corresponds to an outdoor overall sound pressure level of 96 to 104 dB. The implication of these results is that aircraft-generated sound pressure levels of approximately 100 dB can induce structural vibrations of a magnitude sufficient to exceed the threshold of vibration detection for occupants inside their homes. These observations compare favorably with the International Standard Organization (ISO) minimum complaint criteria for building vibration.

PASSENGER ACCEPTANCE

Emphasis is on the development of a ride quality model which includes the interactive effects of noise with multifrequency and multiaxis vibration. Example results are summarized in figure 6 where successive constant discomfort curves (DISC curves) ranging from 1 to 6 are presented in terms of the D-weighted sound pressure level and the vertical vibration level in g_{rms} . A DISC of 1 is approximately the discomfort threshold whereas a DISC of 6 would be relatively uncomfortable. Results suggest that human response is highly dependent upon both noise and vibration level in a very interactive manner.

For example, at high noise levels, the vibration influence is relatively small in comparison to the influence at low levels of interior noise. Current studies are being directed toward quantifying the response to these combined stimuli over a wide range of conditions and incorporating the results into a user oriented ride quality model.

CONCLUDING REMARKS

An attempt has been made to characterize the NASA Langley Research Center program in aircraft noise effects. Community and passenger acceptance studies involving unique laboratory facilities as well as field investigations are being conducted to define and quantify human response to aircraft noise. The results provide criteria for reduction of community and passenger noise (and vibration) as well as guidance for noise certification and land-use planning.

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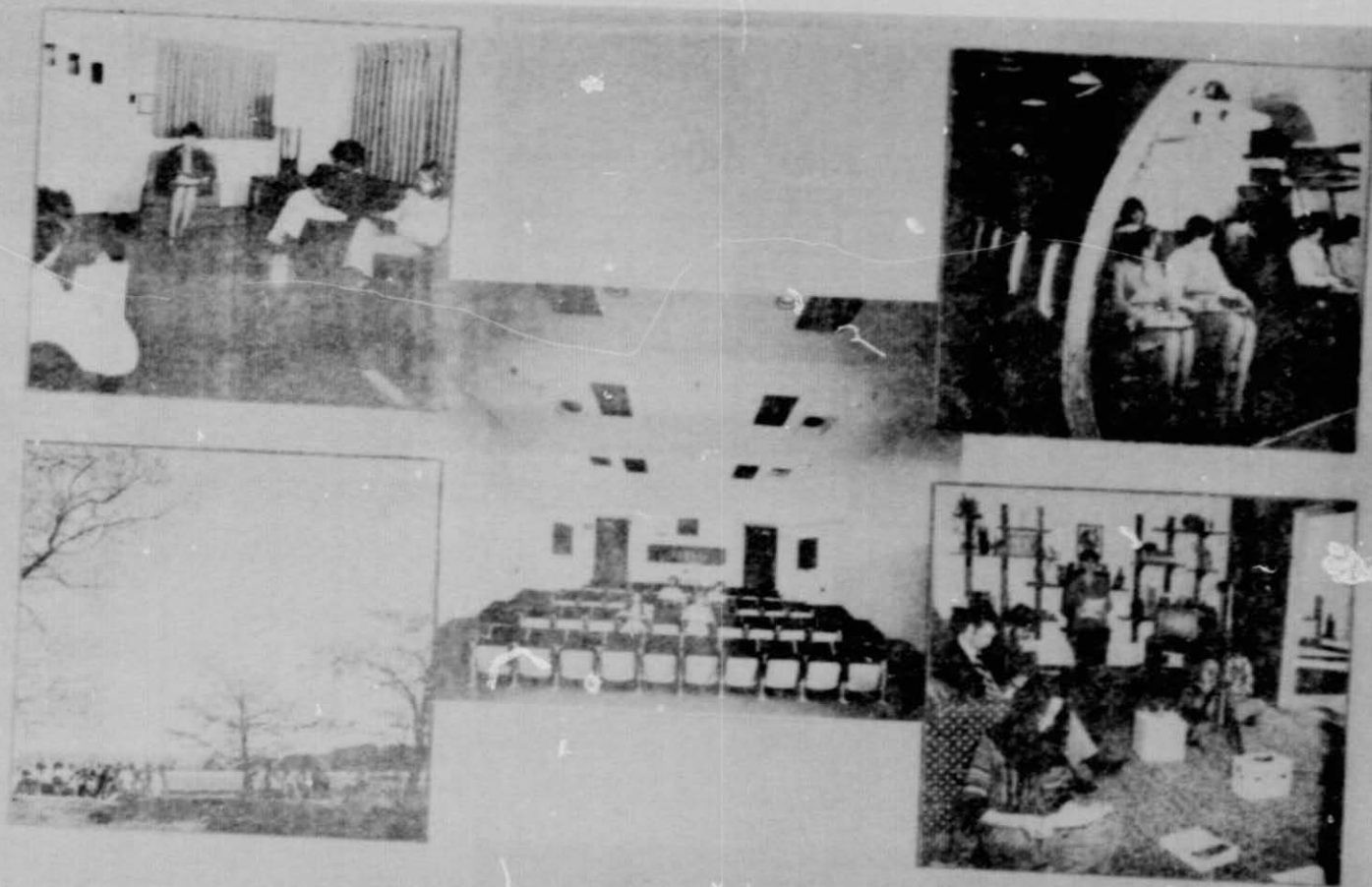


FIGURE 1.- LABORATORY AND COMMUNITY STUDIES OF AIRCRAFT NOISE EFFECTS.

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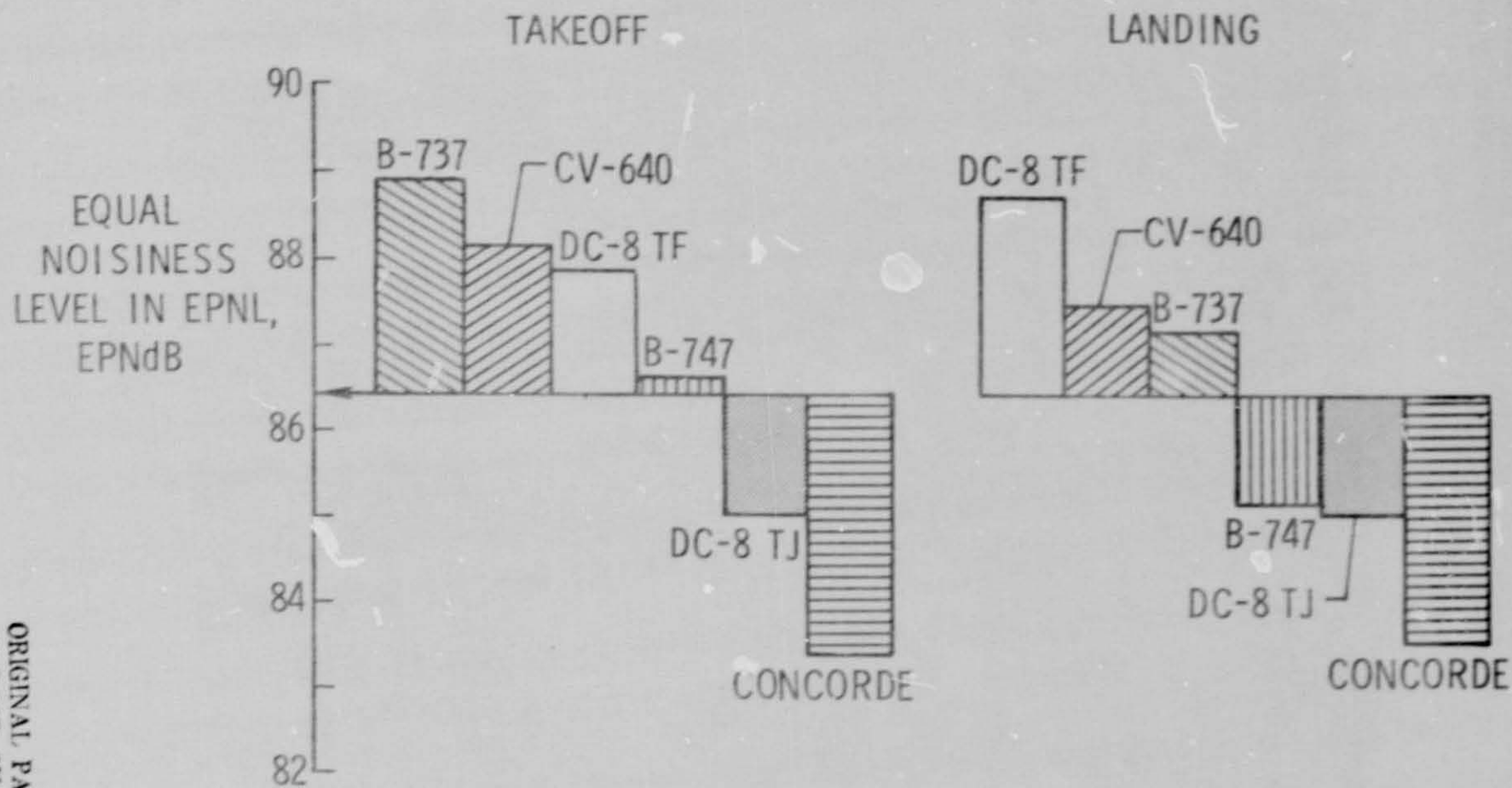


FIGURE 2.- QUANTIFICATION OF SINGLE-AIRCRAFT EVENTS.

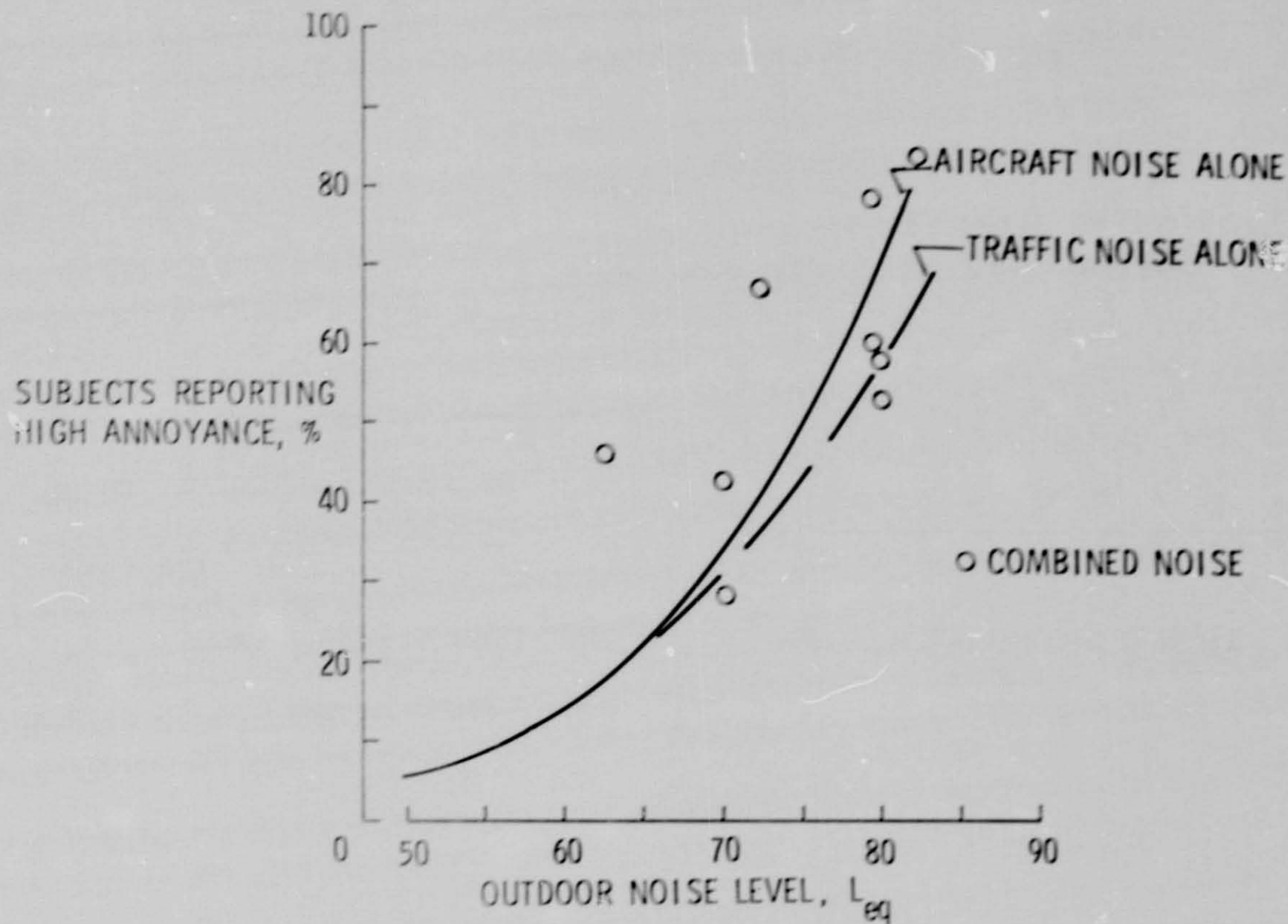
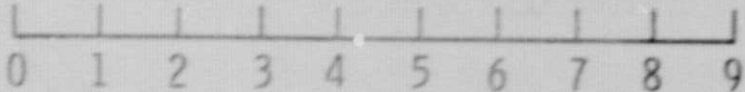


FIGURE 3.- QUANTIFICATION OF COMBINED NOISE SOURCES.

FLYOVER NO.	DETECTION		ANNOYANCE		
	YES	NO	YES	NO	
— VIBRATION —	—	—	—	—	ANNOYANCE RATING OF FLYOVER  0 1 2 3 4 5 6 7 8 9
RATTLE	—	—	—	—	
NOISE	—	—	—	—	

ANNOYANCE RATING: 0 - ZERO ANNOYANCE
9 - MAXIMUM ANNOYANCE

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FIGURE 4.- SUBJECTIVE RESPONSE RATING FORM USED IN COMMUNITY STUDY.

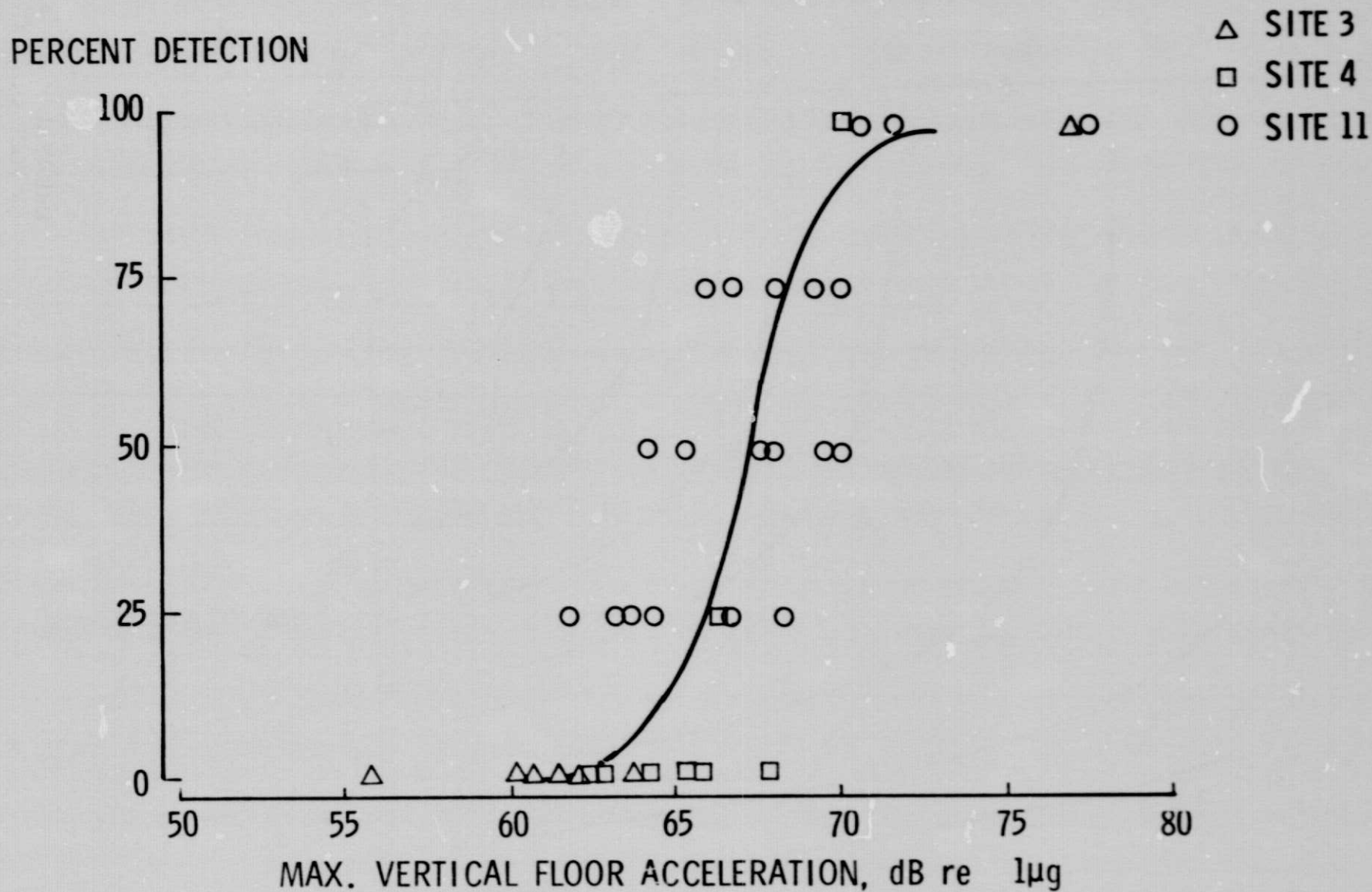


FIGURE 5.- VERTICAL FLOOR ACCELERATION DETECTION THRESHOLD.

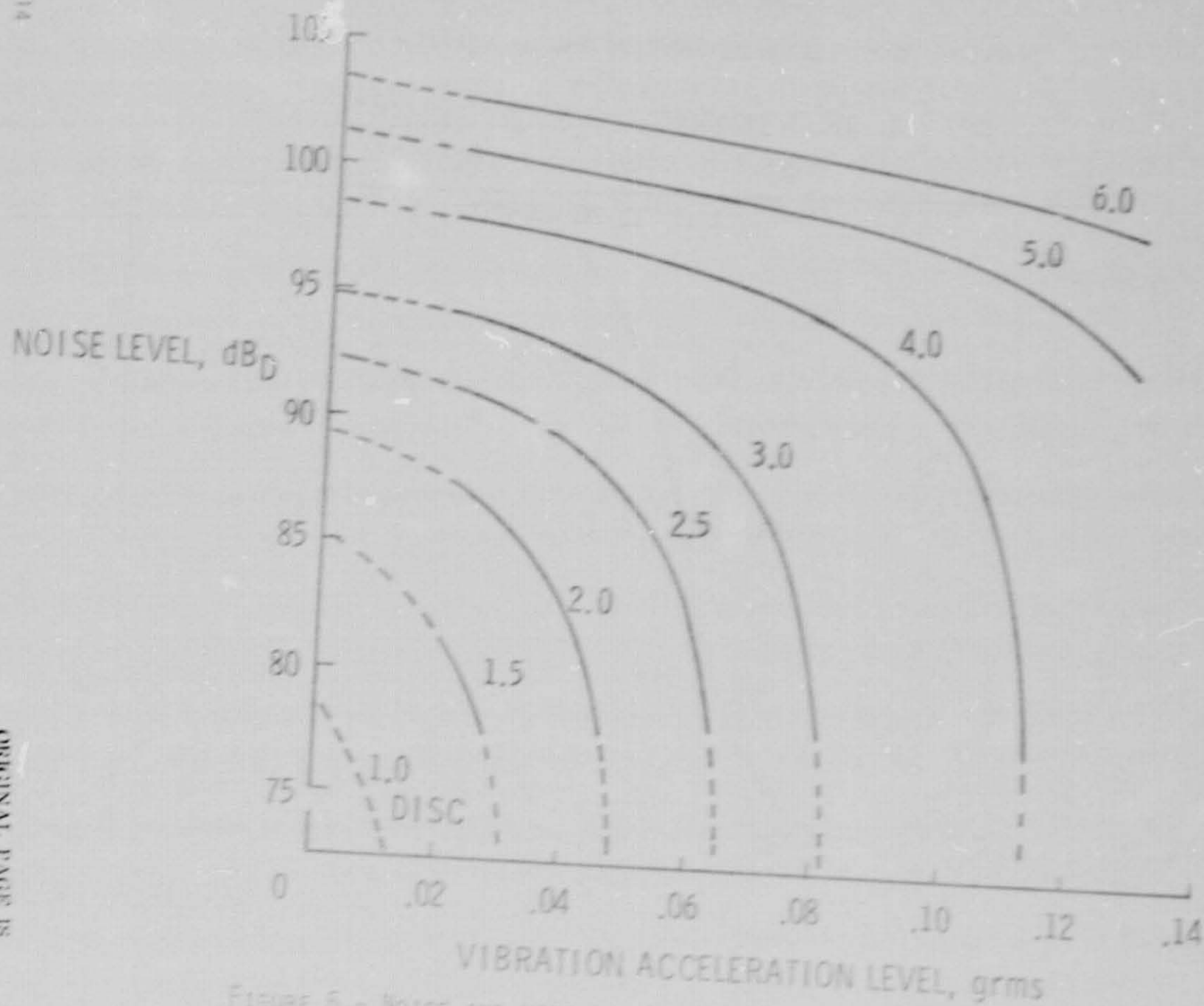


FIGURE 6.- NOISE AND VIBRATION LEVELS FOR CONSTANT DISCOMFORT.